This material is based upon work supported by the National Science Foundation under Grant #1901852. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Introduction to SCADA for Renewables
(A Six Module Course)

Course Learning Objectives

1. **Describe** SCADA system basics and important differences with other control systems
2. **Demonstrate** competency of the key components of a SCADA system and their functions
3. **Describe** the different communication systems used in SCADA
4. **Demonstrate** competency of the role and capabilities of operator interfaces
5. **Demonstrate** competency of implementing SCADA in real world applications, specifically renewable energy applications (install, operation, maintenance)
6. **Identify** emerging technical trends, shifts, and innovations impacting SCADA and its application in the renewable energy sector

Introduction to SCADA for Renewables

Course Outline / Curriculum Learning Modules:

Module 2 – SCADA Components and Functionality

Learning Objectives

- **Identify** common field instruments and sensors and understand how they are used in a SCADA system
- **Discuss** syncing and sourcing sensor devices and actuators
- **Wire** intelligent electronic devices and controllers
- **Understand and evaluate** various PLC and RTU controller functions and programming
- **Configure** controllers for basic communication to workstations and wider networks
- **Program** controllers and smart devices (write program, perform calculations, perform scaling operations, perform tagging operations, etc.)
- **Configure** and program a RTU to communicate with the master system
- **Understand** role of the Master Terminal and how it monitors and/or controls other components
- **Configure** and program a Master Terminal to communicate with various system components
- **Understand** role of the HMI in communicating information to/from the user/operator and design and configuration best practices for a HMI
- **Distinguish** between proprietary systems and standards based general purpose communications networks
- **Investigate** communications between smart sensors and various controller devices
- **Discuss** standard TCP/IP network equipment such as switches and routers

Module 2 – SCADA Components and Functionality
Pre-requisites

Students should have completed the following courses prior to taking Module 2 or have equivalent work experience:

- Introductory DC/AC Electrical Circuits
- Digital Electronics Fundamentals
- Programmable Logic Controllers (recommended)

References and Additional Learning Material

- https://blog.norcalcontrols.net/solar-pv-plant-operations
  Resource blog for SCADA solar applications

- Stuart A. Boyer, SCADA: Supervisory Control and Data Acquisition, 4th Edition, International Society of Automation, ISBN 978-1-936007-09-7

- Mini S. Thomas, John A. McDonald, Power System SCADA and Smart Grids, CRC Press, ISBN 978-1-4822-2675-1

SCADA System Components (1)

SCADA is a collection of hardware and software components:

- **Sensors, meters, switches, etc.**
- **Remote Terminal Unit (RTU)**
- **Programmable Logic Controller (PLC)**
- **Master Terminal Unit (MTU)**
- **Human Machine Interface (HMI)**
- **Communication networks and protocols**

Basic SCADA System Components

- SCADA enables data collection from one or more distant facilities and facilitates sending control instructions to such facilities.

- SCADA was developed to monitor and control very large distributed process facilities such as energy grids, remote gas or oil pumping facilities, etc.

- SCADA typically is NOT used for factory control and monitoring – PLCs (Programmable Logic Controllers) or DCSs (Distributed Control Systems) work better for the factory control.

SCADA System Components Purpose

Hardware / Software Components	Purpose
Input Field Devices: sensors, switches, meters, etc.	To perform data collection.
Output Field Devices: Motor controls, valve controls, etc.	Devices that can be controlled remotely.
Remote Terminal Units (RTU), Programmable Logic Controllers (PLC)	Receives instructions and performance targets from MTUs. Performs immediate control of field devices. Collects data from field devices and communicates data (or totalized data) to MTU.
Master Terminal Unit (MTU)	Sends process targets to RTUs. Monitors data from RTUs to ensure that targets have been reached. Alerts operator about system conditions.
Human Machine Interface (HMI)	Display system components status. Relay operator input to MTUs.
Communication networks and protocols	Enable communication between: RTU/PLC and field devices; RTUs and MTU; MTU and HMI

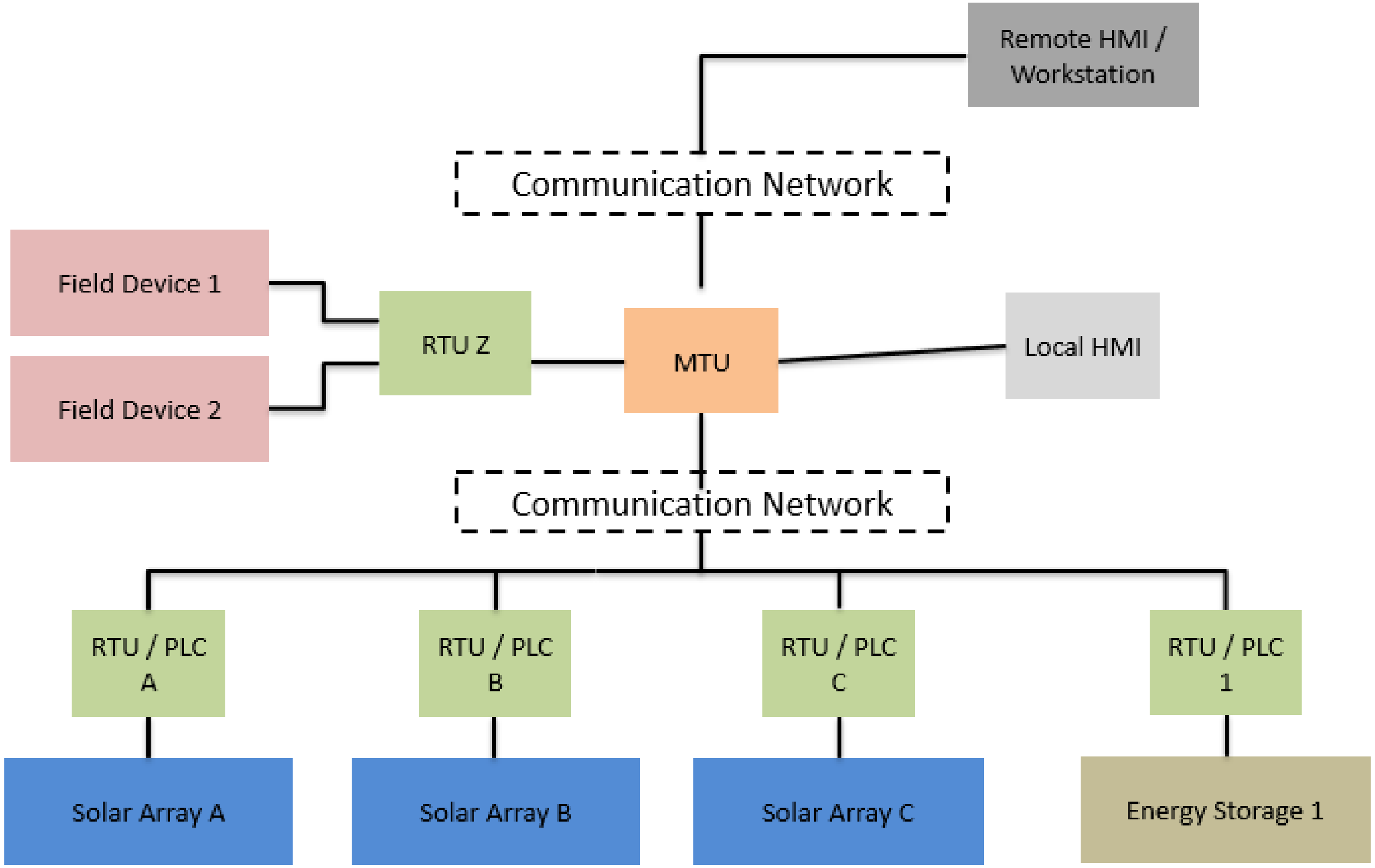
SCADA System Components (2)

SCADA is a collection of hardware and software components:

These are the various components mentioned below:

- **Sensors, meters, switches, etc.**
- Remote Terminal Unit (RTU), Programmable Logic Controller (PLC)
- Master Terminal Unit (MTU)
- Human Machine Interface (HMI)
- Communication networks and protocols

SCADA System Diagram Example (1)



Input Field Devices: Discrete vs Analog

- Input field devices, such as sensors and switches, provide real time process signals to a RTU or PLC.

- Input filed devices can produce discrete or analog inputs to RTU/PLC:

  Discrete inputs - can only have two states – ON and OFF (binary 1 or 0). Discrete inputs are typically powered by 24VDC or 120VAC power supplies. Examples of discrete inputs are from switches and some sensors.

  Analog inputs - are typically produced by sensors and meters and provide continuous DC voltage (0-5V, 0-10V) or DC current (0 – 50mA, 4 – 20mA) values. Analog inputs require specialty analog input cards (for PLCs) with built-in A/D converters.

Input Field Devices: NO vs NC Switches

- **Normally Open (NO)**

  OPEN- WHEN INACTIVE

  CLOSED-WHEN ACTIVATED

Normally open switches are open when inactive and closed when activated.

- **Normally Closed (NC)**

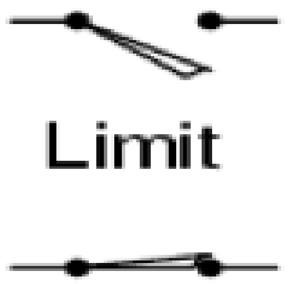
  CLOSED-WHEN INACTIVE

  OPEN-WHEN ACTIVATED

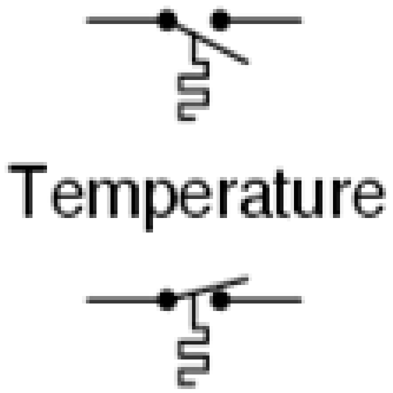
Normally closed switches are closed when inactive and open when activated.

Input Field Devices: Examples of Discrete Mechanically Operated Switches (1)

- **Limit switch**
  Limit switch position control is used to
  - Govern carriage
  - movement range Count parts
  - Parts tracking / zones and
  - Initiate operating sequence

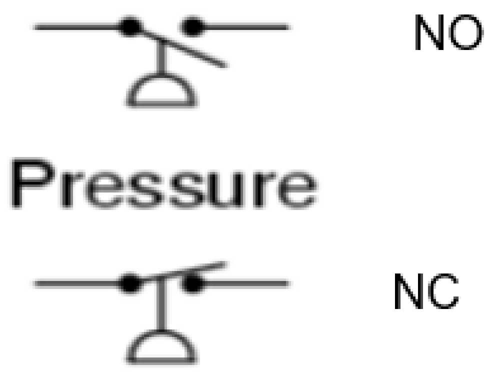


- **Temperature Switch**
  Temperature switch can be bi-metallic, liquid, or vapor based. Most have adjustable preset adjustable actuation point. Some may also have separate de-activation point.

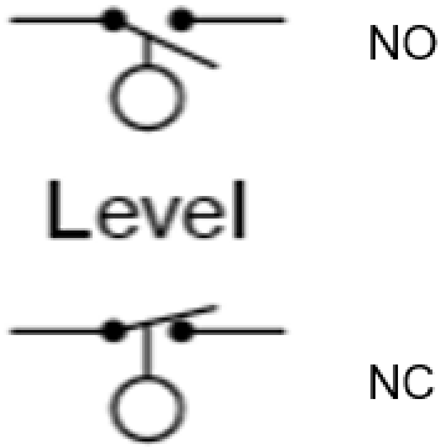


Input Field Devices: Examples of Discrete Mechanically Operated Switches (2)

- **Pressure switch**
  Limit switch position control is used to:
  - Govern carriage movement range
  - Count parts
  - Parts tracking / zones
  - Initiate operating sequence



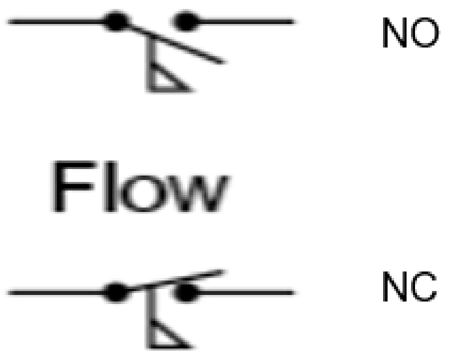
- **Level Switch**
  Level switch is activated by level change in liquids. The switch uses a float to determine the action. Below curtain level, fluid is added to the chamber. Above curtain level, fluid entry stops. It can be used to control pump motor action or solenoid pipe valves.



Input Field Devices: Examples of Discrete Mechanically Operated Switches

FLOW SWITCH:

- Flow switch is activated by a CHANGE in flow of liquid or gas.
- A flap in a pipe or passage is rotated or pushed aside by moving fluid.
- All of these are examples of DISCRETE (ON/OFF) inputs.



I/O Field Devices: Examples of Discrete Electro-Magnetically Operated Switches

I/O Field devices- examples of Discrete Electro Magnetically Operated switches:

- **Relays**

  Relay is an electro-magnetic switch controlled by the PLC/RTU with moderate currents (0.3A to 10A) and voltages (up to 240 V).

- **Contactors**

  Contactor is an electro-magnetic switch controlled by the PLC/RTU. It is used to provide ON/OFF contacts for circuits with heavy current loads (10A to 100's A).

Input Field Devices: Sensors

- SENSOR – is a transducer that receives and responds to a signal or stimulus from a physical system AND produces a signal which could be used by a control system.

  Sensors can detect the following properties: mechanical, electrical, magnetic, thermal, optical, chemical, audio, atomic, etc.

- Examples: proximity detectors (inductive or capacitive), light/optical/IR sensors, light/dark level sensor, pressure sensor, temperature sensor and many more.
- Sensors can produce both discrete and analog electrical signals.

Output Field Devices: Actuators

OUTPUT FIELD DEVICES:

- **ACTUATORS:**

ACTUATOR is a device that is responsible for moving or controlling a mechanism or system. It is controlled by a signal from a control system or manual control.

Examples:

- Pneumatic valve actuator; Motor starter etc.

SCADA System Components (3)

SCADA is a collection of hardware and software components:

- Sensors, meters, switches, etc.
- **Remote Terminal Unit (RTU)**
- **Programmable Logic Controller (PLC)**
- Master Terminal Unit (MTU)
- Human Machine Interface (HMI)
- Communication networks and protocols

Remote Terminal Unit (RTU)

Remote Terminal Units (RTUs) are microcomputer-based with special equipment to:

- Interface with the long-range communications link to MTU (Master Terminal Unit)
- To interface with the sensors, actuators, and perform calculations in the process.

Since modern RTUs need to perform some control functions, as well as interface functions, Programmable Logic Controllers (PLCs) can be used in place of RTUs in SCADA systems.

RTU/PLC Functions

Remote Terminal Unit (RTU) or Programmable Logic Controller (PLC) performs the following main functions:

- Communicates with MTU (Master Terminal Unit):

When MTU requests, RTU sends signals to open/close valves, turn switches on/off, start/stop motors, outputs analog or digital signals (such as set points) or outputs pulse trains to move stepper motors.

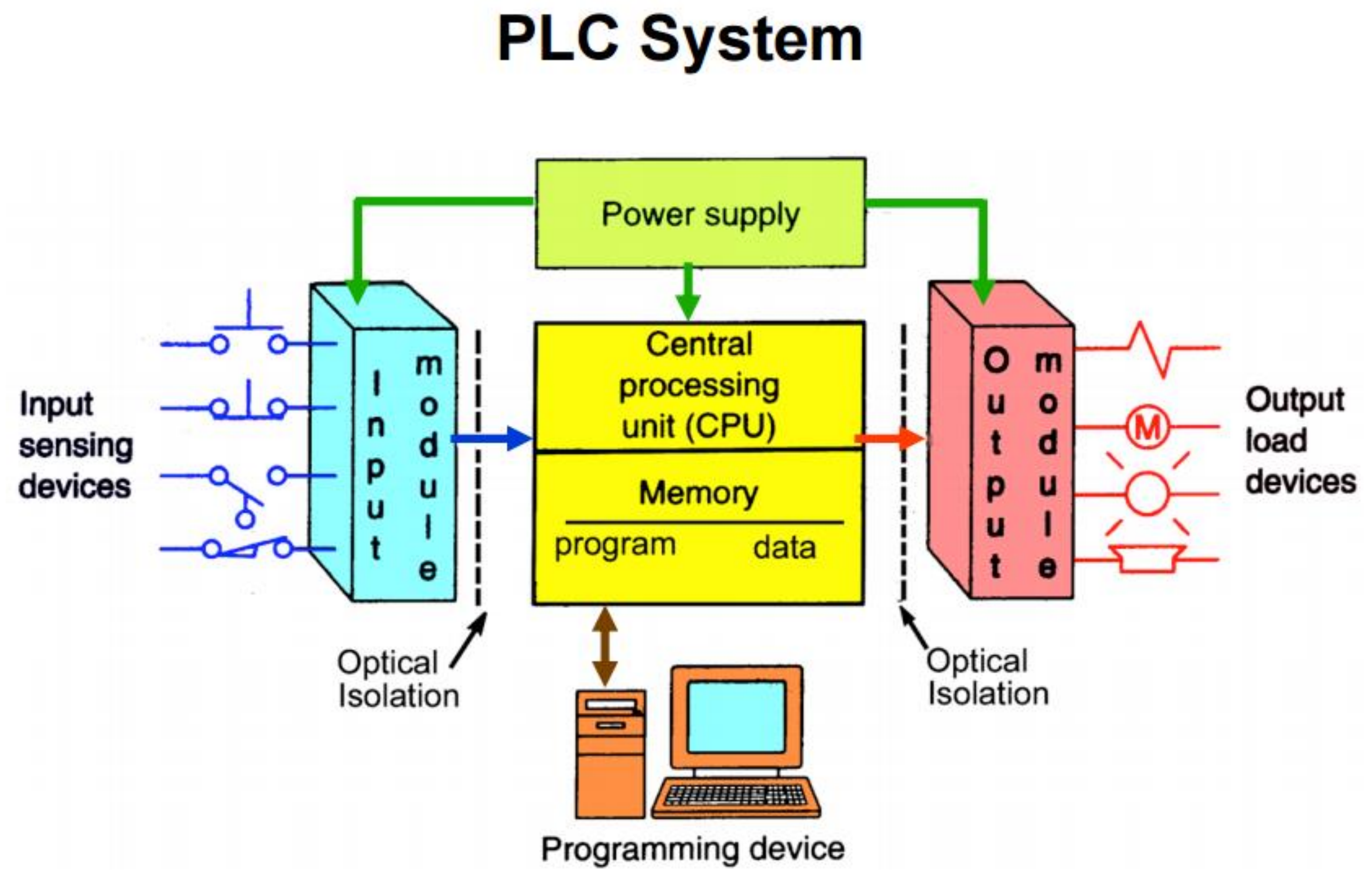
- Communicates with each of the field sensors and actuators that it is connected.
- Gathers information from the field: analog or digital values, alarm and status points, metered amounts.
- Converts data into digital form and keeps this information available for MTU.
- Solves algorithms to act as controller or a pulse totalizer for functions that cannot wait for decision from MTU.

RTU vs Controller (PLC)

Initially, RTUs (analog RTUs) performed only the first two functions. Now, electrical controllers, such as PLCs (Programmable Logic Controllers), can be used in place of dedicated RTUs that allow additional functionality:

- Fluid flow totalizing or electrical energy flow totalizing
- Interactive valve positioning or interactive pneumatic controls positioning
- Other control functionality such as PID loops (example – PID loops in oil refining process) that require powerful CPU processing capabilities

Programmable Logic Controllers (1)



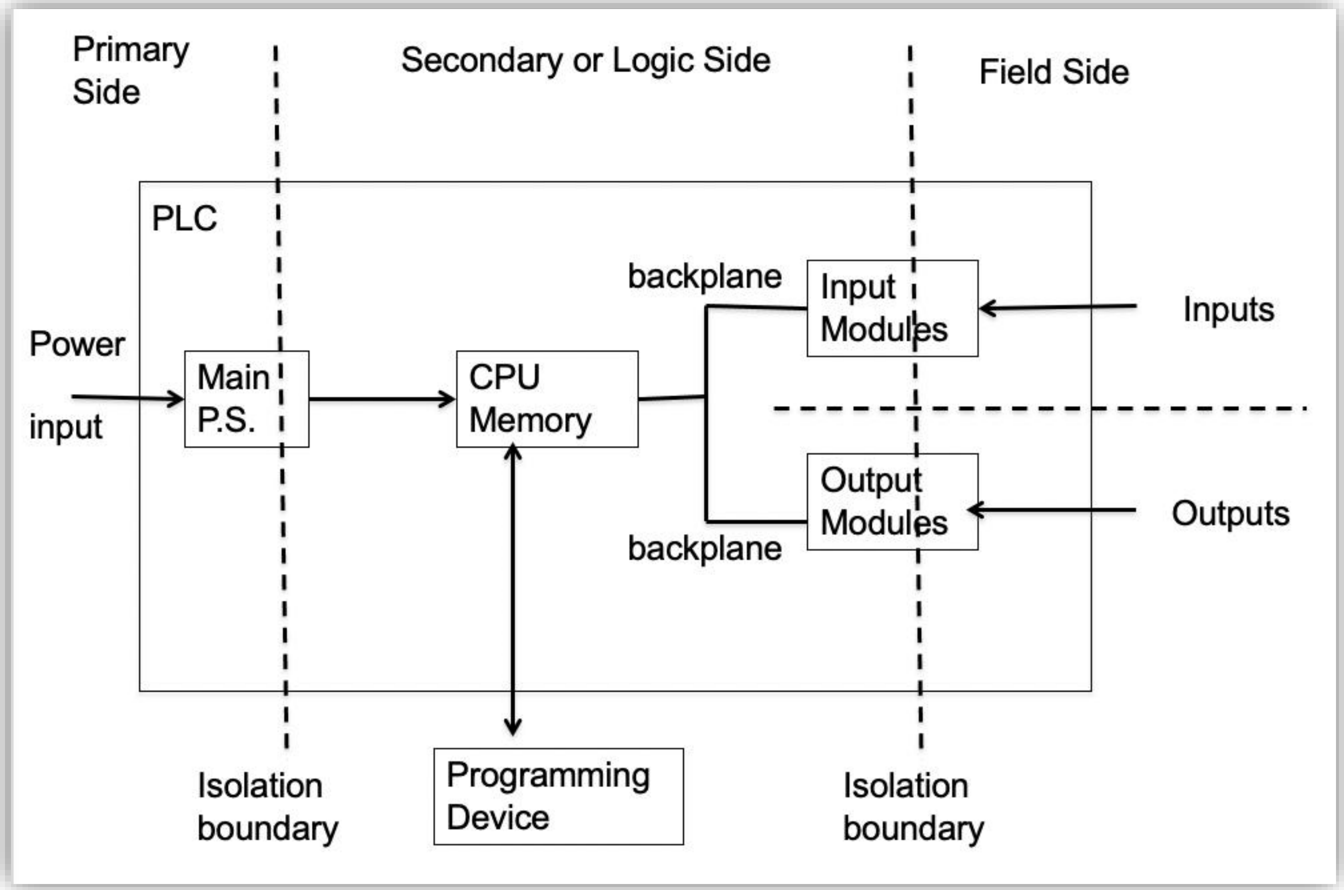
Programmable Logic Controllers (2)

PLC is essentially a computer with similar components, architecture, operation, but with enhanced handling of input/output field devices. PLC has:

- Central Processing Unit (CPU) with ALU, registers, instructional decoder, clock and control signal circuit.
- Memory to store firmware, program and data.
- I/O modules (input/output) – AC or DC discrete I/O, AC or DC analog I/O. specialty I/O.
- Power supply (5 VDC for CPU, limited 12/24 VDC for I/O.
- Base (Rack or Backplane or Chassi) provides electrical contacts and databus on the back of the rack.
- Specialty modules – I/O modules with separate CPU, such as high speed counter or Ethernet module.

Programmable Logic Controllers (3)

What really separates PLC from a regular computer and makes it suitable for harsh industrial environment is presence of isolation boundaries as shown on this figure.



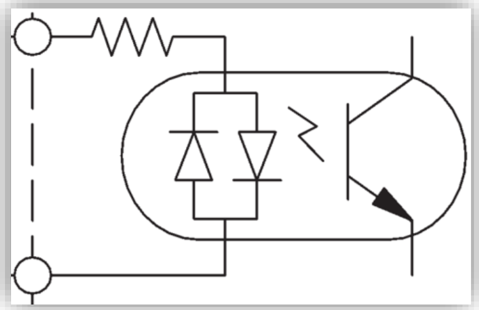
Source: www.AutomationDirect.com

Programmable Logic Controllers (4)

- Electrical isolation between primary / secondary / field sides and different I/O is important for safety, so that fault in one area does not damage another area.

- A transformer in the power supply provides magnetic isolation between primary and secondary sides.

- Opto-couplers in I/O modules provide optical isolation between CPU and I/O in the input/output circuits. This isolates logic circuitry (CPU) from the field side (machinery).



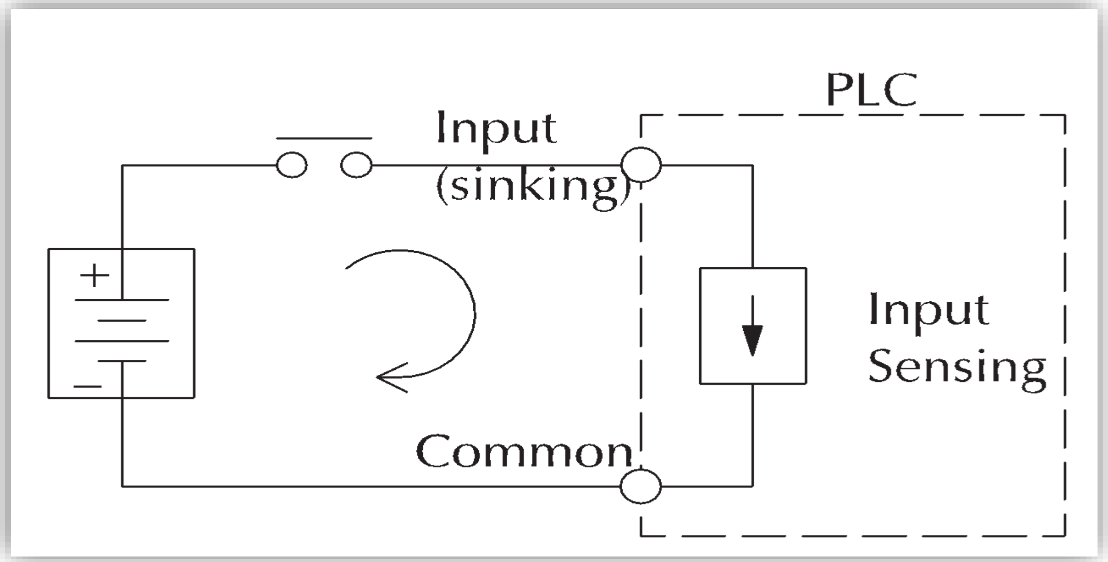
Source: www.AutomationDirect.com

Discrete inputs are isolated from discrete outputs as well.

PLC: Sinking vs Sourcing

- Sinking/Sourcing is only applicable to DC powered field devices.

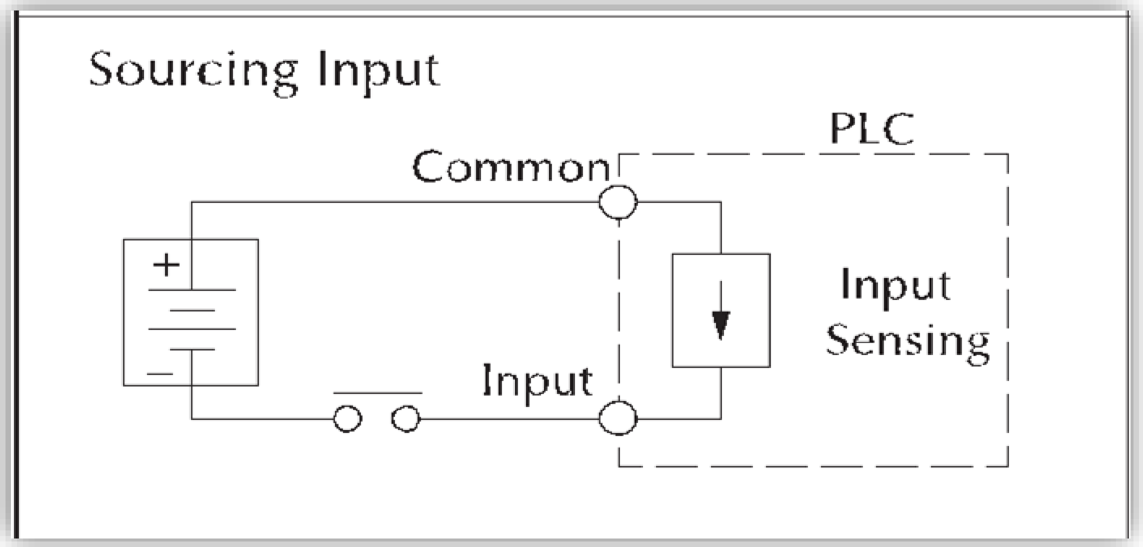
- For example, **Sinking** PLC input is defined as input circuit with uninterrupted path to supply ground.



Source: www.AutomationDirect.com

I/O Field Devices: Sinking vs Sourcing (1)

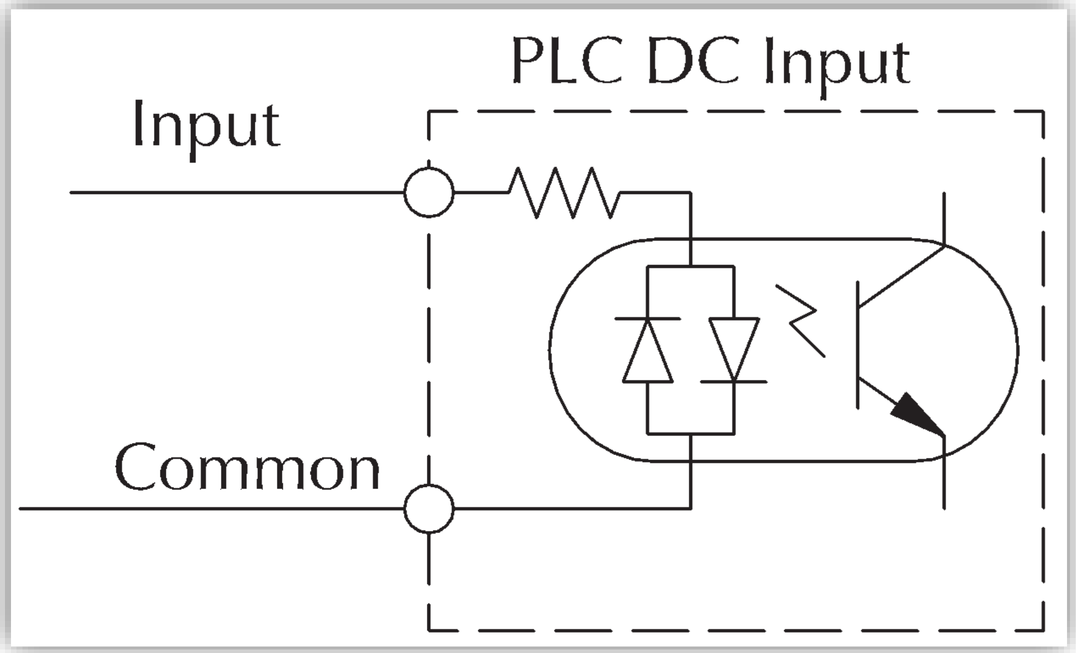
- **Sourcing** PLC input is defined as input circuit with uninterrupted path to supply source (positive terminal).



Source: www.AutomationDirect.com

I/O Field Devices: Sinking vs Sourcing (2)

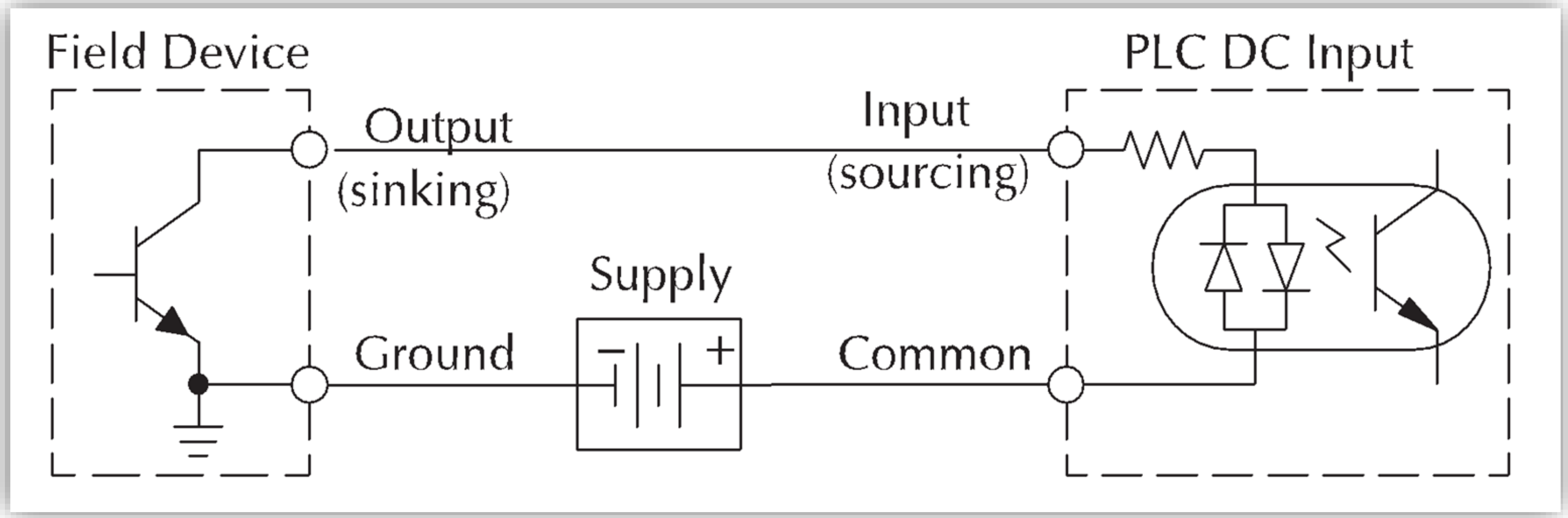
- Many newer PLCs with DC inputs can be wired as either sinking or sourcing due to dual diodes in the opto-isolator.



Source: www.AutomationDirect.com

I/O Field Devices: Sinking vs Sourcing (3)

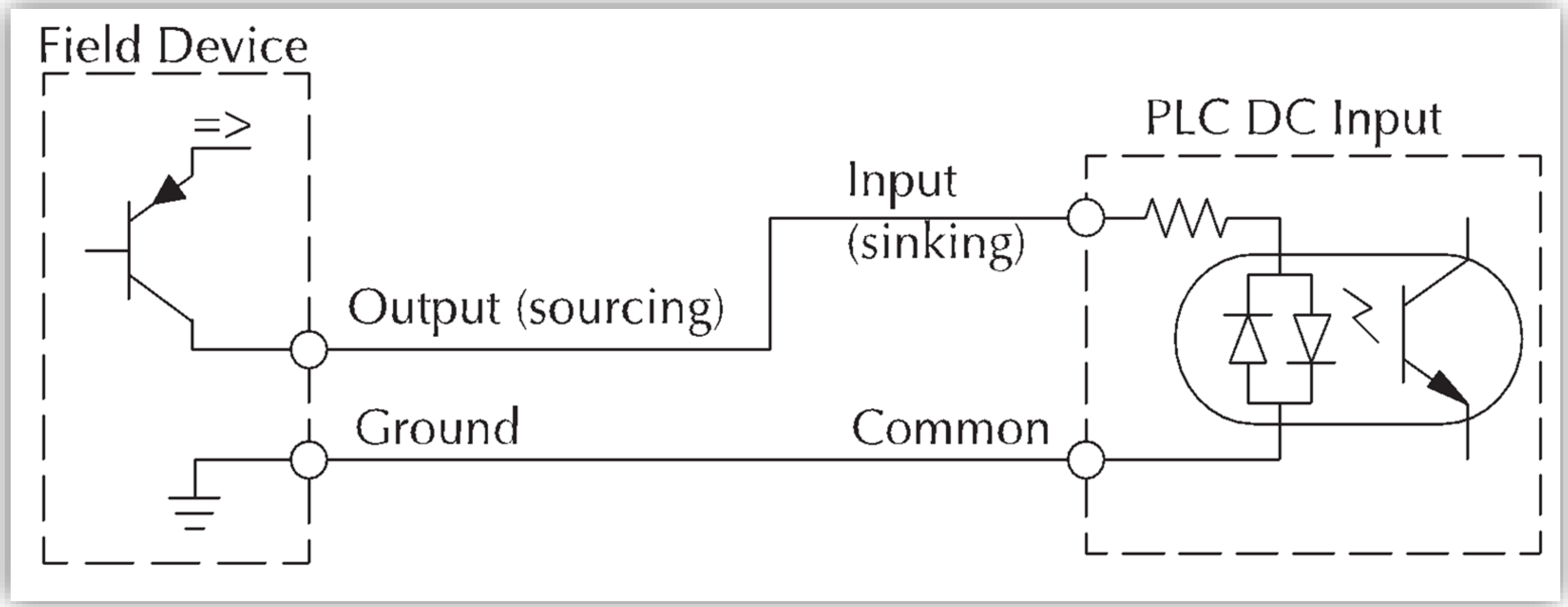
- Most Sourcing PLC discrete input circuits can be paired up with Sinking Field Devices, such as sensors (except AB PLCs which use terminology of sourcing PLC inputs being paired up with sourcing field devices).



Source: www.AutomationDirect.com

I/O Field Devices: Sinking vs Sourcing (4)

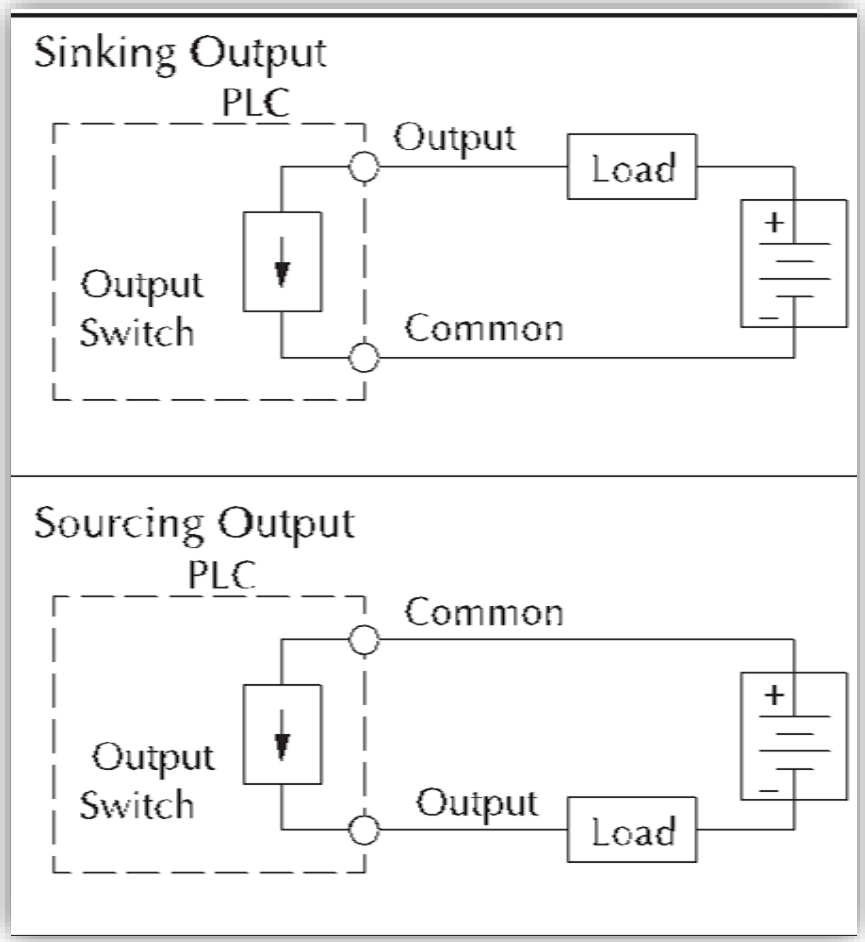
- Vice versa, Sinking PLC discrete input circuits can be paired up with Sourcing Field Devices, such as sensors.



Source: www.AutomationDirect.com

I/O Field Devices: Sinking vs Sourcing (5)

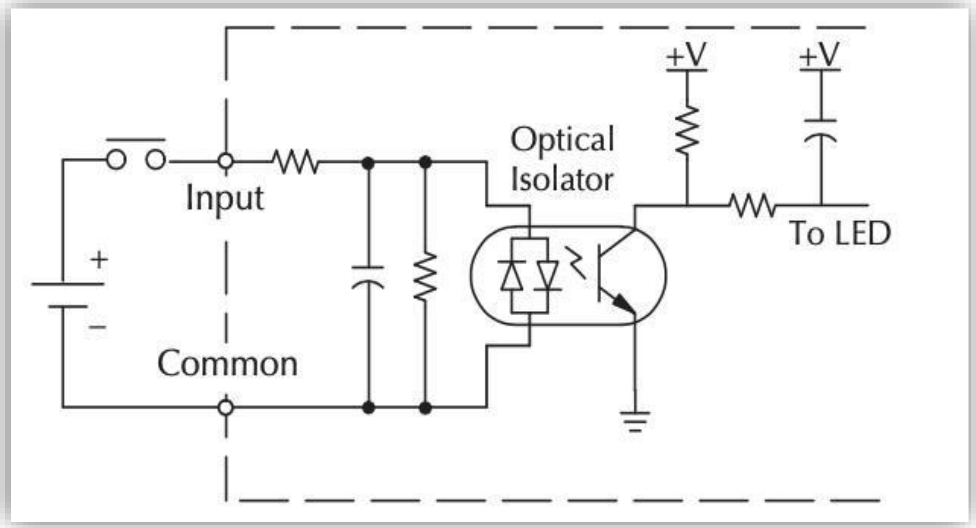
- Similar to DC PLC inputs, DC PLC outputs can be wired as sinking or sourcing (using 12VDC or 24VDC typical power supplies):



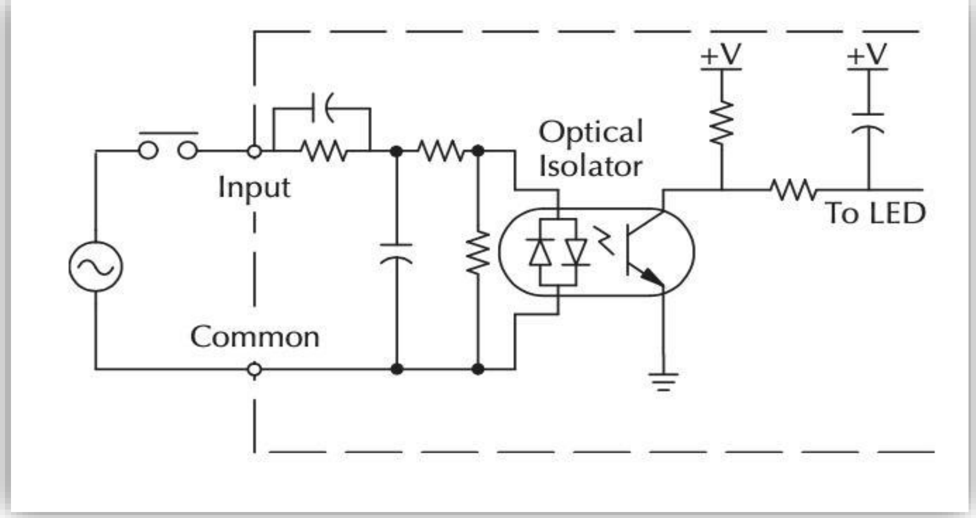
Source: www.AutomationDirect.com

Input Field Devices: AC vs DC

- **Only DC PLC Inputs** – sinking, sourcing or both. PLC DC input circuits are usually built using solid-state electronic components.



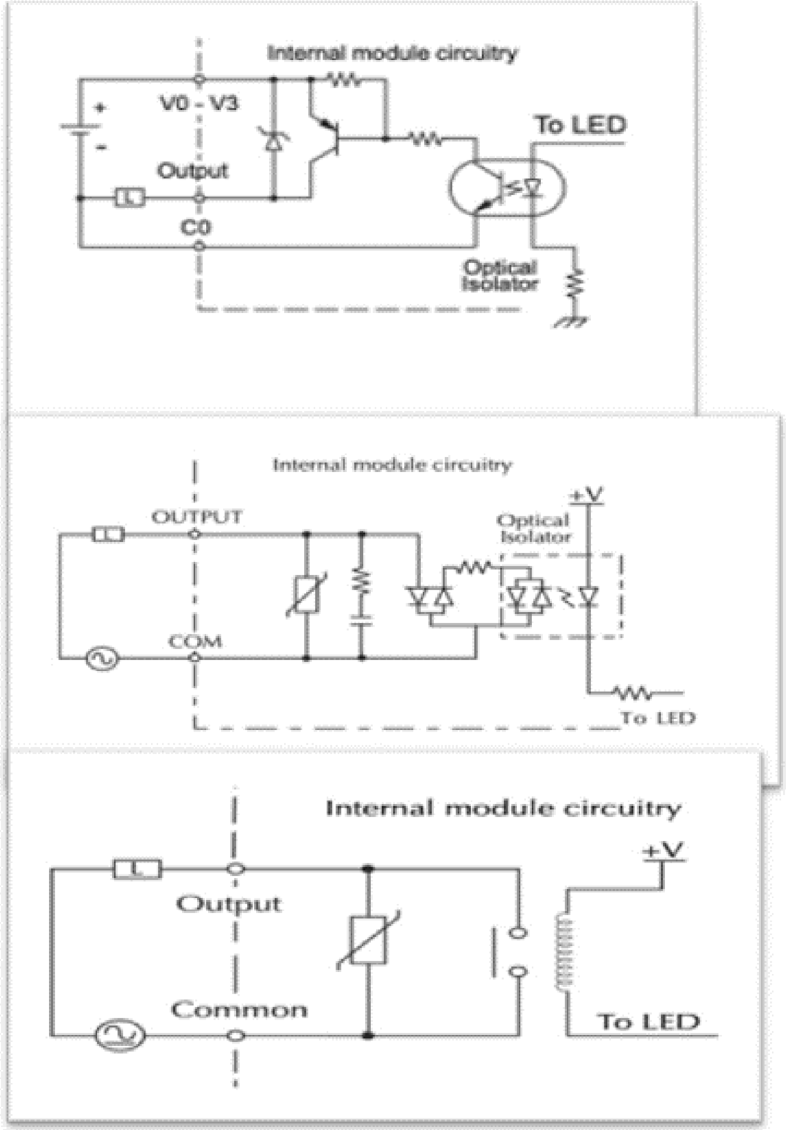
- **Only AC PLC Inputs** – are typically built using solid-state electronic components. Sinking and sourcing is NOT applicable to AC inputs.



Source: www.AutomationDirect.com

Output Field Devices: AC vs DC

- **Only DC PLC Outputs** – sinking or sourcing. PLC DC output circuits are usually built using solid-state transistor components.
- **Only AC PLC Outputs** – are typically built using solid-state triacs as part of the output circuitry. Sinking and sourcing is NOT applicable to AC outputs.
- **AC or DC PLC Outputs** – are built using relays in the output circuitry which allows them to use outputs powered by either DC or AC power supplies.



Source: www.AutomationDirect.com

I/O Field Devices to PLC Wiring

- **Wire sizes**– AWG 14 – AWG24, usually AWG 20 – 24.
- **Energizing I/O** – AC or DC power supply must be used with inputs and outputs (need to check specs to choose appropriate power supply). PLC may provide auxiliary power supply to power inputs and limited number of low-power outputs.
- **Wire Tagging** – each wire should be tagged/labelled to indicate which switch/sensor or load and which PLC input/output port it is connected to. This is very important for system troubleshooting.
- **Copper Wire** is usually used since signals are low-voltage electrical. In some applications, **Shielding** needs to be added over the copper wire to prevent electromagnetic interference or noise.

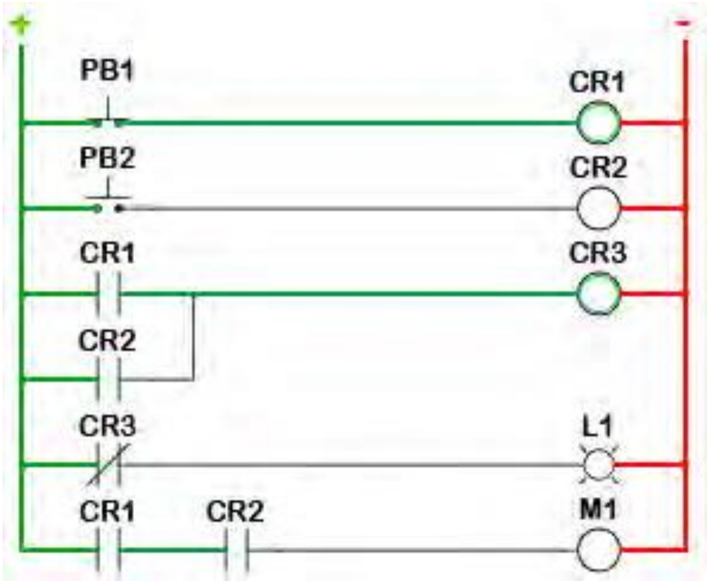
PLCs: Programming

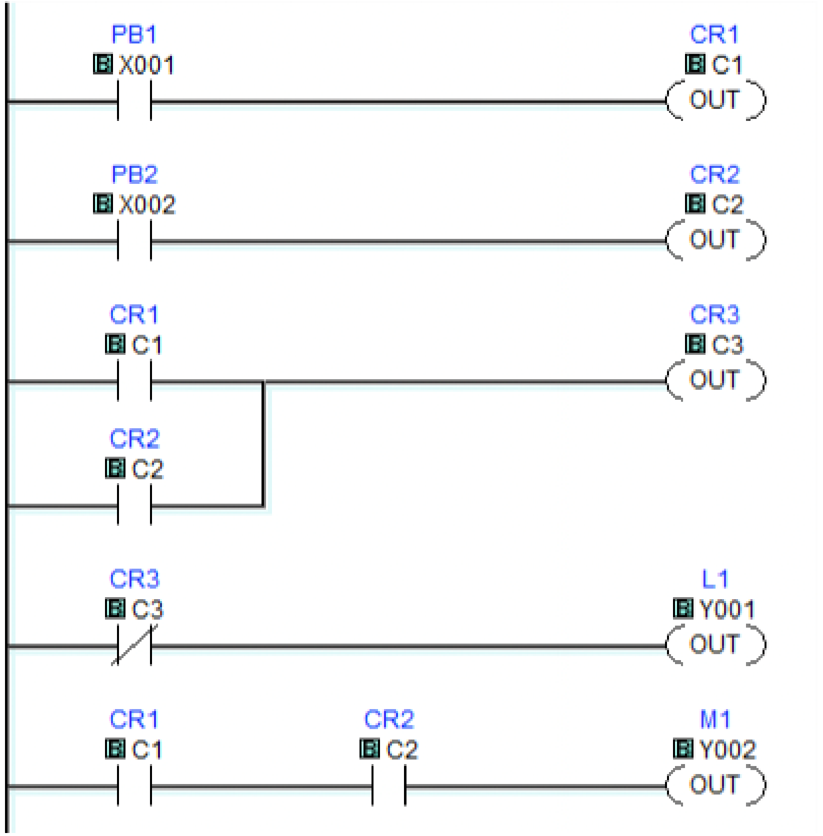
PLCs are programmed by using one of the following programming methods:

- Ladder Logic – is a graphical language that resembles relay ladder logic used by electricians. This is the most widely used PLC programming language.
- Structured text.
- Instruction lists.
- Sequential function charts.
- Function blocks.

PLCs: Ladder Logic Programming (1)

The following two examples show relay ladder logic vs PLC ladder logic diagrams (both look like ”rungs” of the ladder):





PB – push button

CR – control relay

PLCs: Ladder Logic Programming (2)

- Left rail represents power rail.
- Right rail – ground rail.
- Outputs are energized when logic contacts provide closed path for the electrical current to flow from left rail to right rail.
- If PLC is in the run mode, it will:
  - scan all inputs (and record input status values in PLC memory),
  - scan and perform all ladder rungs (use status of each input stored in the memory and update all memory location corresponding to the outputs),
  - update physical outputs (open or close output relay or solid state switches that will energize/de-energize field devices).
- If PLC in the program mode, it will only scan inputs and update input memory locations.

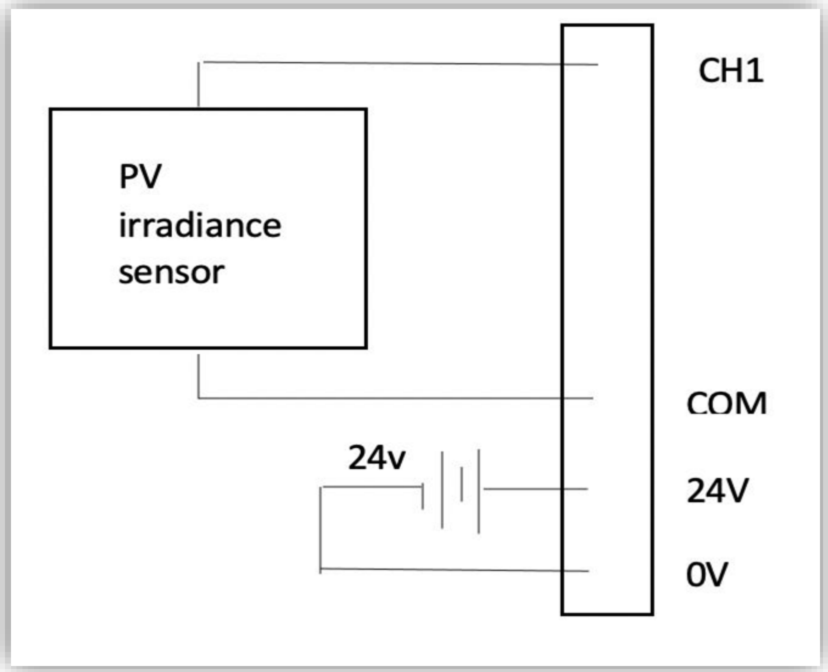
PLCs: Configuring/Programming Discrete Inputs / Outputs

- There is no special config required for discrete inputs or outputs.
- If push button PB1 is connected to input terminal X001 of the PLC, memory location X001 can be used in the ladder logic program to address this input.
- If motor starter is connected to discrete output Y1, it can be addressed in ladder logic as Y1 for output coil or set/reset instructions.

PB – push button
CR – control relay

PLCs: Hardware / Configuring/Programming for Analog Inputs / Outputs in DL06 PLC (1)

- Analog inputs and outputs typically require special I/O cards.
- Diagram shows wiring diagram for the 0.0 - 1.0 V PV Irradiance Sensor connected to the Analog Voltage Input card for DL06 PLC. PV Irradiance Sensor serves as a power source since it generates DC voltage between 0.0V and 1.0V for irradiance level between 0 W/m^2 and 1000 W/m^2. The analog input card is rated for 0 – 5VDC input voltage.



PLCs: Hardware / Configuring/Programming for Analog Inputs / Outputs in DL06 PLC (2)

- Analog inputs/outputs require special configuring.
- Ladder logic code for DL06 PLC below configures format (BCD or binary) of the incoming data and number of active channels on the card (0 – 8). K100 that is stored in memory location V700 indicated 1 channel in BCD format.
- It also stores address of memory location where data from this input card (O2000) in the memory location V701 assigned to the input card located in slot 1.

PLCs: Hardware / Configuring/Programming for Analog Inputs / Outputs in DL06 PLC (3)

- Next ladder logic block inputs and stores multiplication constants that will be used in the rescaling calculations.
- A/D converter in the analog input card is going to take the voltage between 0V and 5V and convert it to the numerical value between 0 and 65535.
- We need to convert this abstract number to the corresponding irradiance level with 65535 corresponding to irradiance level of 5000 W/m^2.

PLCs: Hardware / Configuring/Programming for Analog Inputs / Outputs in DL06 PLC (4)

- The last block of ladder logic performs re-scaling calculations and store value in units of W/m^2 in the memory location V2100.

PLCs: Hardware / Configuring/Programming for Analog Inputs / Outputs in DL06 PLC (5)

- Finally, the value of solar irradiance, stored in V2100, can be use to energize/de-energize water pump (connected to output Y11) and to update status of control bit (C2) to be displayed on the operator touch-screen panel.
- Configuring/Programming instructions syntacsis shown here is specific to DL06 PLC, but similar programming steps would need to be done on other PLCs to process analog I/O.

SCADA System Components (4)

SCADA is a collection of hardware and software components:

- Sensors, meters, switches, etc.
- Remote Terminal Unit (RTU)
- Programmable Logic Controller (PLC)
- **Master Terminal Unit (MTU)**
- Human Machine Interface (HMI)
- Communication networks and protocols

Master Terminal Unit (MTU)

The center of SCADA system is Master Terminal Unit (MTU) which:

- Issues all commands to communication equipment and RTUs
- Receives information requested from RTUs
- Gathers all data from RTUs
- Stores some information (usually in totalized form)
- Passes information to associated systems
- Interfaces with operators via HMI (Human Machine Interface hardware)

MTU Communications Interface

Communications Interface Requirements:

- Use the same communications medium that RTU uses to send information to MTU
- Use the same protocol as the RTU (usually proprietary protocols)
- In MTU-RTU communications, usually utilizes Master-Slave communications with MTU being a master (that initiates all communications) and RTU being a slave (cannot initiate communications)
- In communications with printers and operator screens/HMI, utilizes regular computer communications techniques using open protocols and standard equipment. This is typically done with peer-to-peer communications via local area networks or LANs.
- May pass data to accounting computers, corporate business computers or computer networks.

SCADA System Components (5)

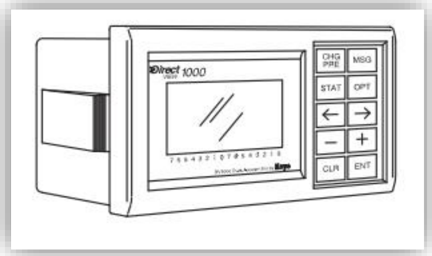
SCADA is a collection of hardware and software components:

- Sensors, meters, switches, etc.
- Remote Terminal Unit (RTU)
- Programmable Logic Controller (PLC)
- Master Terminal Unit (MTU)
- **Human Machine Interface (HMI)**
- Communication networks and protocols

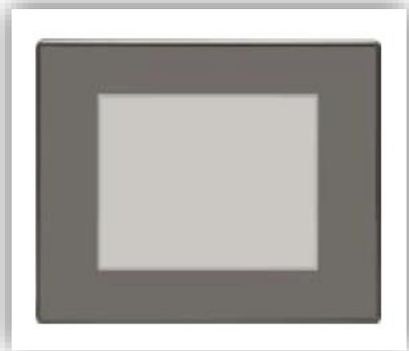
Human Machine Interface (HMI)

Operator can interact with MTU and/or RTU using the following Human Machine Interface (HMI) devices:
Programming devices: computers and hand-held devices (legacy systems).

- Operator interface devices: data entry units, touch-screen panels or larger operator screens.



Data entry unit



Touch-screen panel/screen

Human Machine Interface (HMI) (1)

HMI operator interface devices can be connected to MTUs and/or RTUs using:

- serial communication cables RS-232
- Ethernet cables

HMI operator interface devices can be connected to programming devices (computers) using:

- USB connectors
- Ethernet cables

Depending on the connection type, appropriate communication protocols must be utilized.

Human Machine Interface (HMI) (2)

HMI Video Resources:

- What is HMI?
  https://www.youtube.com/watch?v=kujHQgK352o

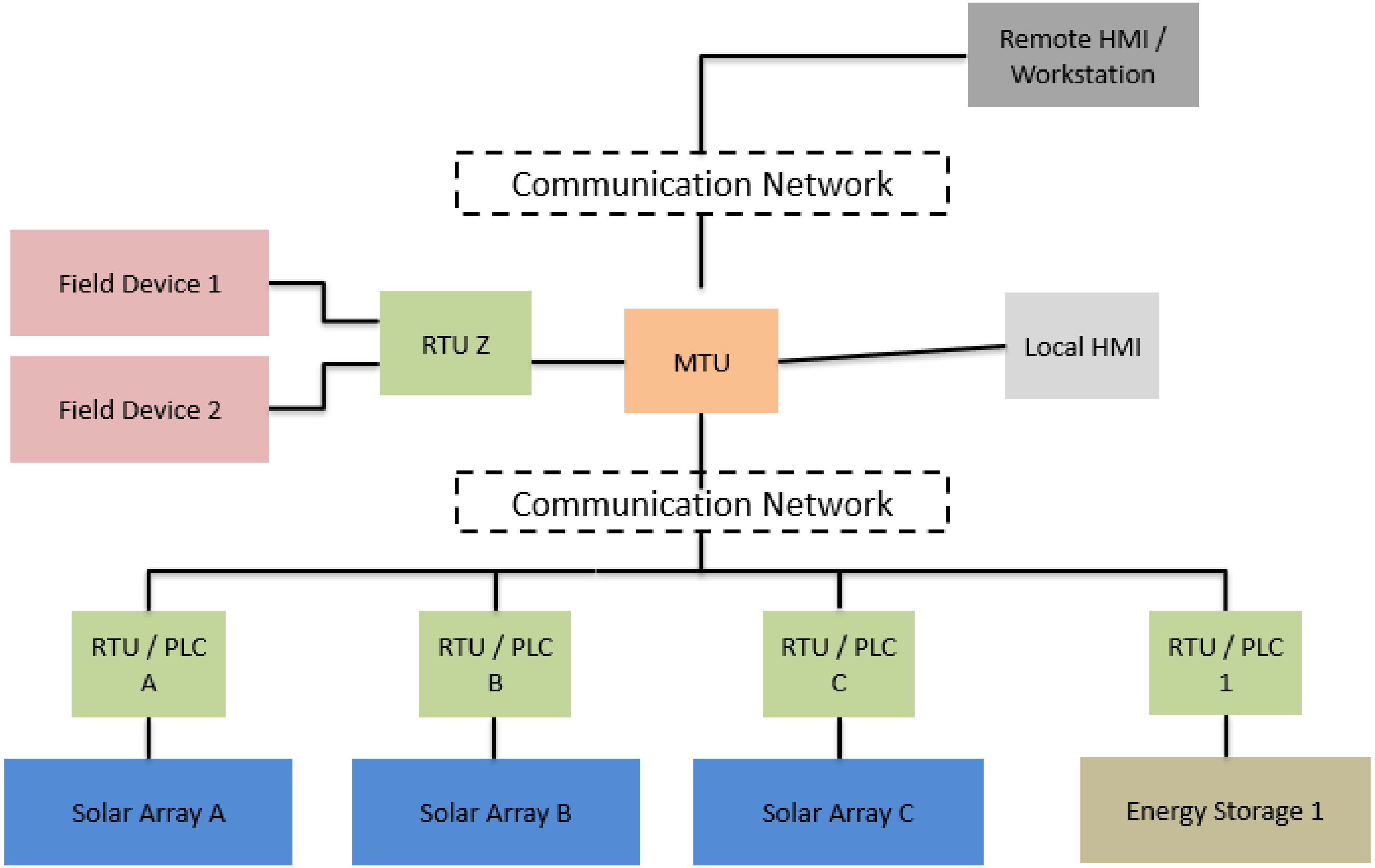
- Example of C-More Touch Screen panel setup and programming using DO-More PLC Software:
  https://www.youtube.com/watch?v=fq5ScU0BI-k&t=183s

SCADA System Components (6)

SCADA is a collection of hardware and software components:

- Sensors, meters, switches, etc.
- Remote Terminal Unit (RTU)
- Programmable Logic Controller (PLC)
- Master Terminal Unit (MTU)
- Human Machine Interface (HMI)
- **Communication networks and protocols**

SCADA System Diagram Example (2)



Communication Networks and Protocols in SCADA Systems (1)

Three rules of communication:

1. Talker and listener must use the same communication medium.

2. Talker and listener must use the same language (communication protocol).

3. Talker must not talk when someone else is talking (communication protocol).

Communication Networks and Protocols in SCADA Systems (2)

Communication network/protocols can be:

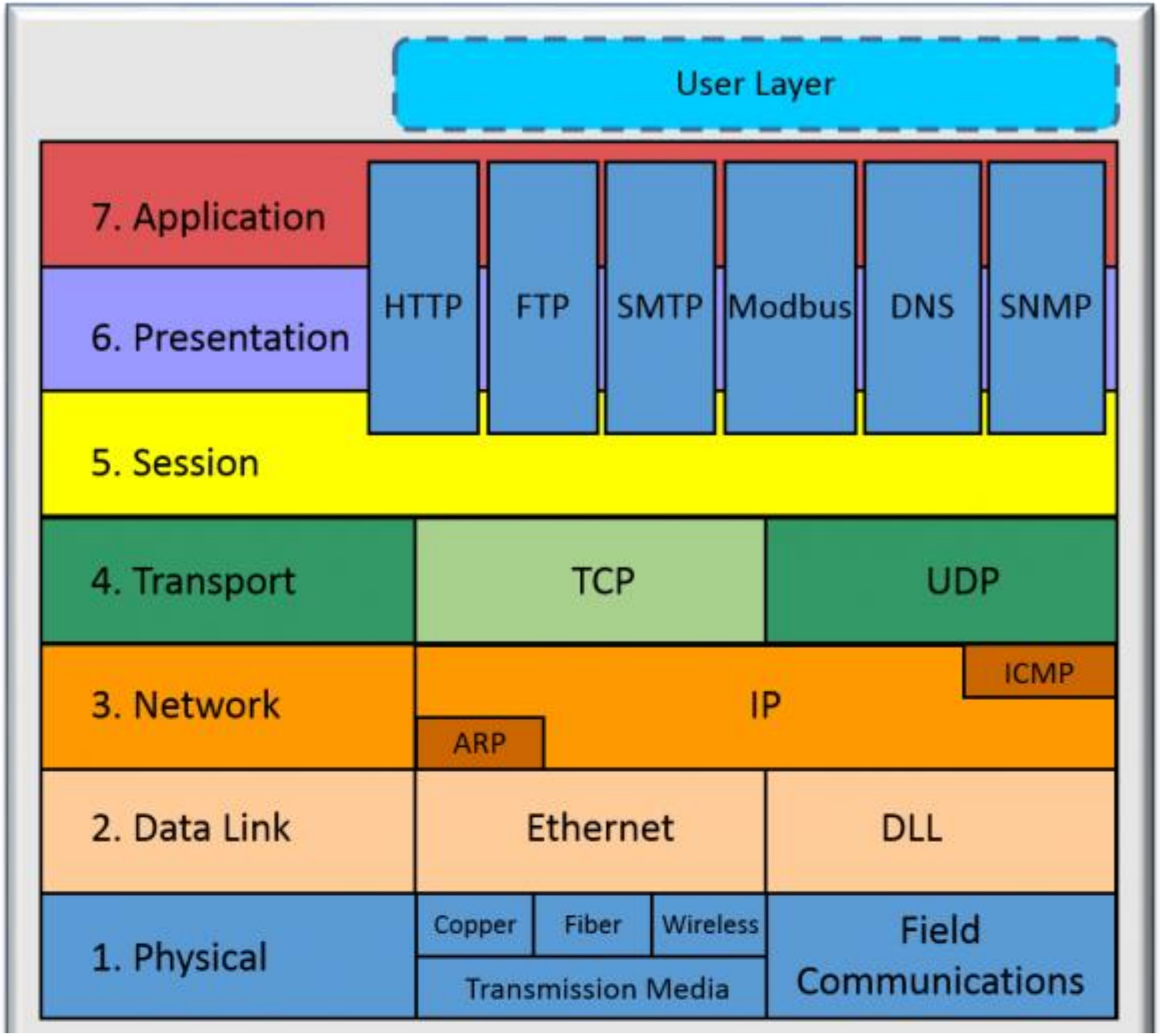
<u>Closed or Proprietary</u>

- Convenient for connecting hardware from the same manufacturer
- Examples: Proprietary protocol for a barcode reader using an RS-232 point-to-point connection or RS-232C or RS-422 physical layer network with the DirectNET protocol

<u>Open Systems</u>

- Are needed to connect systems components from different manufacturers.
- This lead to the development of Open System Interconnection model (first for computers, later for PLCs)

OSI (Open System Interconnection) Model (1)



Source: https://library.automationdirect.com/plc-communications-coming-of-age/

OSI (Open System Interconnection) Model (2)

“The physical layer defines how to connect the upper data link layer in the OSI communications model within a computer/PLC to physical devices. It is basically the hardware requirements with schematics and specifications for successful bit-level communication to different devices.”

The physical layer defines:

- bit rates,
- transmission electrical, light or radio signals,
- flow control in asynchronous serial communication,
- types of cables (communication standards) and the shape of connectors.

Source: https://library.automationdirect.com/plc-communications-coming-of-age/

Serial Communication Standards (1)

RS-232 Standard :

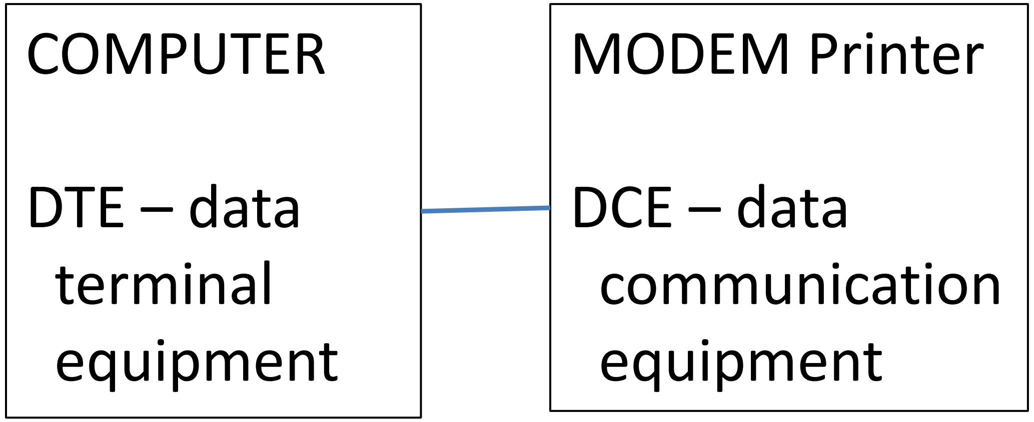
- Introduced in 1962. RS stands for recommended standard
- Other names include
  - TIA-232 (Telecom Industry Association – 232)
  - EIA-232 (Electronics Industry Association – 232)
- This is unbalanced wire (made of single wire, not twisted so that noise does not cancel out equally).
- max length 50’ (at max data rate of 20 Kbps)
- voltages: High (mark) (1) : -3V to -25V
Low (space) (0) : +3V to +25V
- Typical computer voltages: +/-5V (CPU), +/-12V (ex – to run fan motors and other operations)
- Max data rate is 20 Kbps (kbits per second)

Serial Communication Standards (2)

- RS-232 is used for point-to-point communications.
- Such communications have master/slave designation.
- Example : computer/PLC to modem communication

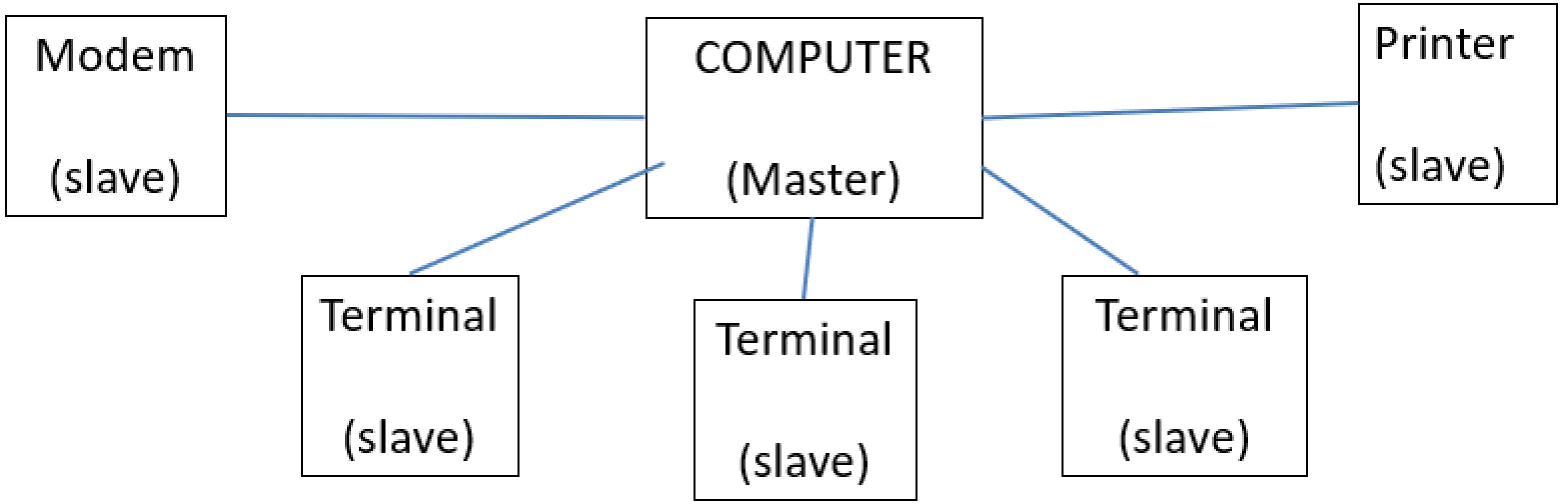
Modem stands for modulator / demodulator:

- was very slow 300 bits per second
- communication byte included start bit + 8 bits data + stop bit, this resulted in transmission speed of about 30 characters per minute.
- Eventually modems went to speeds of 1200 character and 1600 characters per minute.



Serial Communication Standards (3)

RS-232 were used in Star Topology computer network systems (still point-to-point, still fairly short distances)



To go longer distances – need more current I

Serial Communication Standards (4)

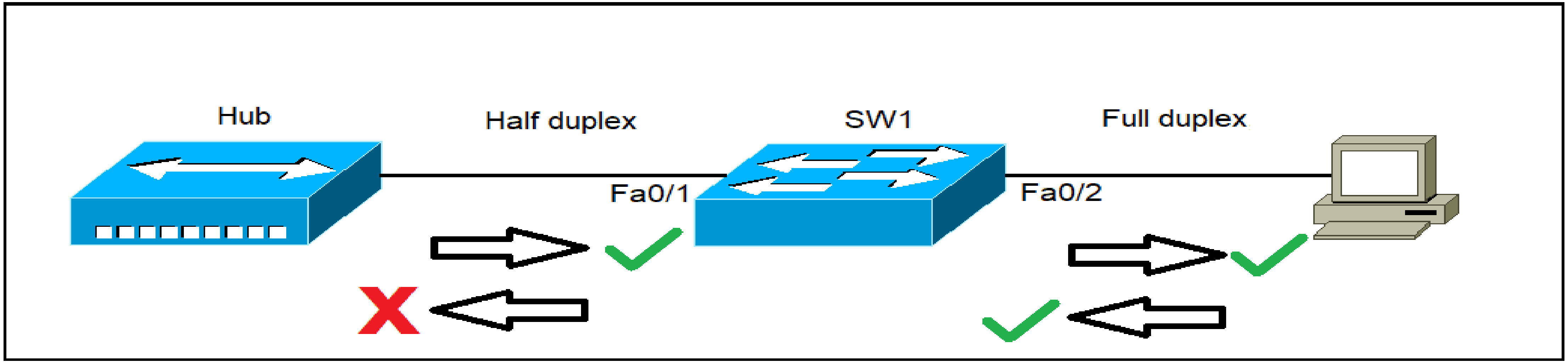
<u>RS/EIA/TIA-423 Standard:</u>

- This is still unbalanced wire (made of single wire, not twisted so that noise does not cancel out equally).
- It is used for point-to-multipoint communications
- Maximum length is 4000’ (at max data rate of 100 Kbps)
- Maximum line voltage is +/- 6V, but currents are higher than for RS-232
- Max data rate is 100 Kbps

Half Duplex vs Full Duplex

- Half duplex – only transmit or receive (but not both) can be on the same line at the same time.

- Full duplex – transmit and receive can happen at the same time on the same line. For full duplex, two dedicated RS-423 wires are needed.



Source: https://study-ccna.com/half-duplex-and-full-duplex/

Serial Communication Standards (5)

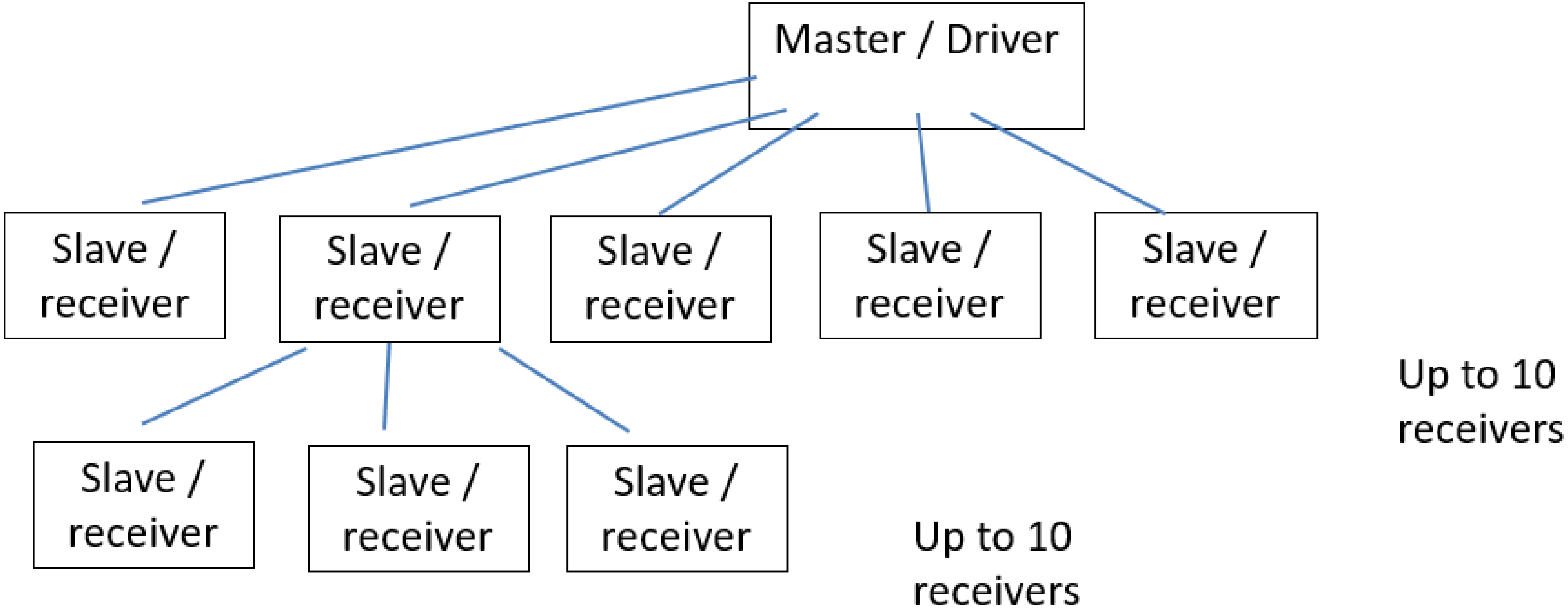
<u>RS/EIA/TIA-422 Standard:</u>

- This is still balanced wire (made of twisted pairs resulting in the same noise cancellation on both wires in the pair). Problem – you need 2 wires for each pin.
- Maximum data rate is 10 Mbps
- Maximum length is 4000’ (at max data rate of 10 Mbps):

  (length x data rate should be less or equal to 1×10^8)
- Line voltages are -0.25V to +6V
- used for point-to-multipoint communications (1 driver/master to up to 10 receivers/slaves)

Serial Communication Standards (6)

STANDARDS : RS/EIA/TIA-422

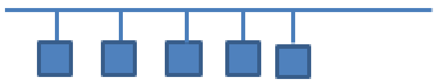


Serial Communication Standards (7)

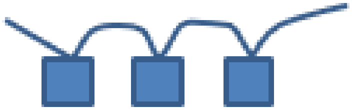
RS/EIA/TIA-485 Standard:

- This is a balanced wire (made of twisted pairs resulting in the same noise cancellation on both wires in the pair). Problem – you need 2 wires for each pin.

- It is used for multipoint-to-multipoint communications:
  - up to 32 drivers
  - up to 32 receivers



Standard configuration



Daisy-chain configuration

- Maximum length is 4000' (at max data rate of 10 Mbps)
- Line voltages are -7V to +12V (and has highest currents)
- Slow – for example, with 90 devices, it takes up to 1 sec to communicate with all

OSI Model : Datalink Layer

- DATALINK LAYER
  - node to node data connection / transfer
  - Media Access Control (MAC) for Ethernet: MAC address is unique number assigned to each piece of hardware by manufacturer)
  - Logical Link Control (LLC)
- Examples:
  - PPP (point-to-point-protocol)
  - IEEE 802.3 (standard devices Ethernet card)
  - Appletalk IEEE 802.11 b/g/n (for wireless)

OSI Model : Network Layer

- NETWORK LAYER – functional and procedural rules for transferring variable length datagrams or packets

  IPv4 – Internet started with this
  IPv6 – current Internet IP addressing rules (allows for more / addresses)
  IPX/SPX – old Novel standard (Novel was leader in LANs, invented expandable token ring configuration)

- TRANSPORT LAYER – functional and procedural rules for transferring datagrams/packets from a source to a destination via one or more networks

OSI Model : Transport Layer

- TRANSPORT LAYER - Functional and procedural rules for transferring datagrams/packets from a source to a destination via one or more networks

  TCP – transport control protocol (most common)

  UDP – universal datagram protocol

  Note: LINUX, UNIX, MAC OS – can run network on any physical layer; Windows – is more restrictive

Serial Communication Protocols

A protocol is a set of rules for communication among networked devices. Proprietary protocols are not part of OSI morel. **Some** examples of proprietary serial protocols are (this is not a complete list):

- Modbus RTU or K-Sequence (usually runs on RS-485 serial network)
- DirectNet (runs on RS-232C or RS-422 physical layer network) for PLC-to-PLC and PLC-to-HMI communications

Disadvantage – they are SLOW and will not work for applications demanding high speed or having high data volume.

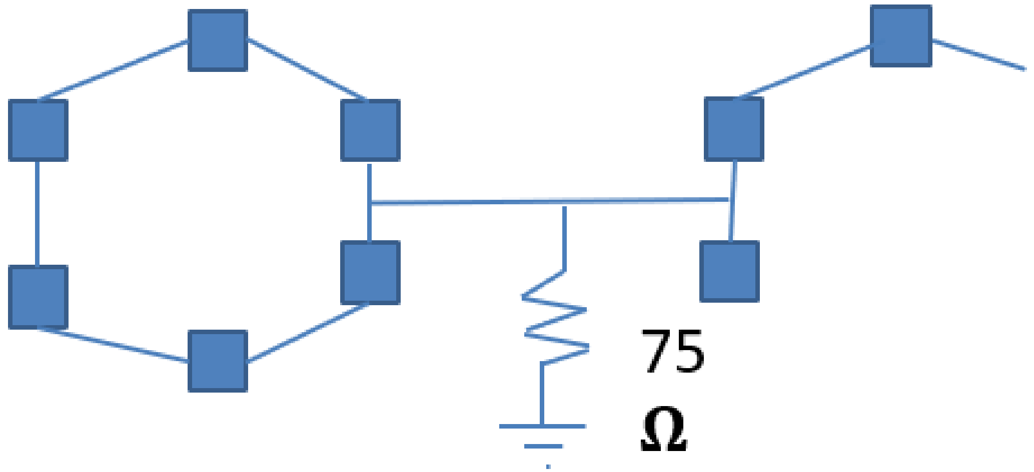
Ethernet Communication Protocols used with PLCs

Some of the Ethernet protocols that are often used in PLC communications:

- ETHERNET/IP
- ETHERNET TCP/IP
- MODBUS TCP/IP
- PROFINET

Early Ethernet Models

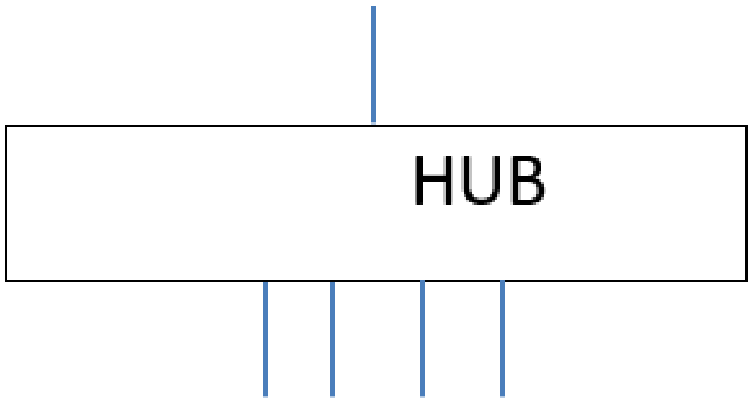
In early days, coax cables were used for token ring configurations.
In a token ring configuration, only 1 computer could talk at a time, then token was passed.



75 **Ω** termination is needed to prevent reflections if connecting to another ring

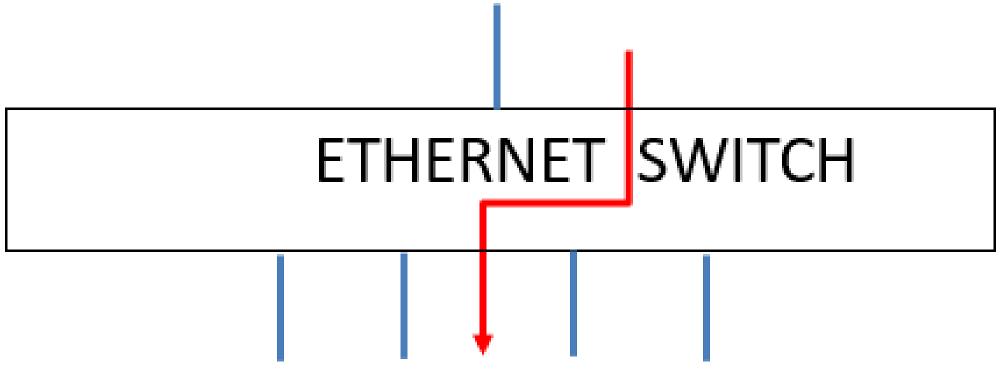
Later Ethernet Models – with HUB

- At a later time, Ethernet was configured using HUBs.
- Every device was connected to the same HUB
- Each device broadcasted to all devices in the network.



Later Ethernet Models – with Ethernet Switch (1)

- At the present time, Ethernet uses Ethernet switches.
- Every device is connected to the same switch.
- Switch can provide communication between 2 devices without broadcasting.



Later Ethernet Models – with Ethernet Switch (2)

How Ethernet Switch switches between devices:

- TDMA/CD – time division multiple access
- CDMA/CD – carrier division multiple access (Internet uses mostly this)
- FDMA/CD – frequency division multiple access
- WDMA/CD – wavelength division multiple access (for fiberoptic cables)

CD – (optional) collision detection

Communications between MTUs, RTUs/PLCs, HMIs and field instruments (1)

Communications between SCADA system components can use:

- Twisted copper wire (serial communications, typically used to connect PLCs to field devices)
- Ethernet cables CAT-5 and 5e, CAT-6 and 6a, CAT-7, CAT-8 and the RJ-45 connectors
- Optical fiber (Ethernet communications mostly)
- Small dedicated radios and/or UHF radios (note, UHF radios only work in the line-of-sight)

Communications between MTUs, RTUs/PLCs, HMIs and field instruments (2)

You will learn more about communications between SCADA system components in Module 3 of this course.

SCADA System Components

Review

SCADA is a collection of hardware and software components:

- **Sensors, meters, switches, etc.**
- **Remote Terminal Unit (RTU)**
- **Programmable Logic Controller (PLC)**
- **Master Terminal Unit (MTU)**
- **Human Machine Interface (HMI)**
- **Communication networks and protocols**

QUESTIONS?